

PERMEABILITY AND STRENGTH OF SOILS
AS AFFECTED BY DISPERSION AGENTS

by

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INTRODUCTION

One of the most important phases of soils engineering is, of course, to find economical ways of improving the properties of soil. The properties of soil can be improved in various ways; however, the purpose of this research was to study the effects of dispersion agents on the permeability and shearing strength characteristics of different types of soils, putting more emphasis on permeability tests.

Permeability is one of the most important physical characteristics of soil because this factor enters into the construction of dams, stability of earth slopes, construction of airports and highways, and many other soil engineering problems.

Permeability of soil can be reduced to very small values either by compacting the soil and thus increasing its density or by the dispersion of clays or colloids by treatment with dispersion agents.

The second process was carried out during this work. Soil was treated by sodium compounds. The purpose was to make the soil more cohesive and impervious to flow of water. This is a result of ion exchange during which the sodium ions took the place of the positive ions attached to the soil particles, thus changing the physical characteristics of the soil.

According to Darcy (Taylor, 9), the velocity of flow through soil is inversely proportional to the diameter of the soil particles. This indicates that if the size of the soil particles can be decreased, the permeability will be reduced because of the smaller effective radius

of the resulting voids.

Along with the permeability tests, unconfined compressive strength tests of dispersant-treated soils were also made to determine the effect of dispersion agents on the strength characteristics in order to obtain a more comprehensive view of the desirability of such treatment.

In order to understand the effect of the dispersion agents on the shearing strength of soils, further studies should be carried out than were possible in the limited time available.

ION EXCHANGE

It is important to have at least some understanding of ion exchange in order to understand clearly what happens to soil when dispersion agents are added.

Ion exchange is a phenomena during which a chemical reaction takes place and thus two ions change places. It is a reversible process depending upon the molecular concentration of the solution. In the soils, this process may take place by the replacement of calcium or hydrogen ions attached to colloidal soil particles by sodium ions from the water solution containing dispersion agents (Lee, 7).

Soil in its natural state is rather of a non-uniform character; it can be dispersed by the use of dispersion agents. For example, a calcium soil is one that is charged with a positive charge. If this soil is treated with a sodium compound which contains anions then there seems to be a reaction between the two unlike charged ions, thus dispersing the soil and arranging its particles in a more uniform way, and also causing flocculation.

This research is a continuation of the work begun by Tekguc (10) on samples taken from the vicinity of Manhattan, Kansas. The geologic test results of the clay minerals in the four samples used are shown in Table 1.

Table 1. Test results of clay minerals.*

Sample	: Clay major mineral groups	: Amount, %
A, B, and D	Montmorillonite	60
	Illite	20
	Kaolinite	20
C	Interstratified, Montmorillonite - Illite	60
	Illite	20
	Kaolinite	20

* The mineral subgroups are the same as major groups.

PROCEDURE

Simple and classification tests were run on all of the four soil samples that were used during this research work. Then the permeability of each soil sample was measured, first with distilled water, and then treating the water with different percentages of three different dispersion agents. A falling head permeameter was used, with a special arrangement, Fig. 1, for heating the water before it reaches the soil sample so that the entrapped air in the sample will be removed before any readings were taken.

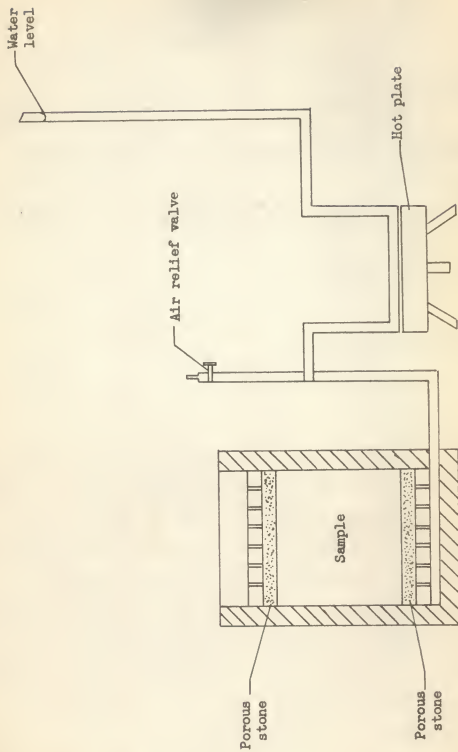


Fig. 1. Falling head permeameter.

Unconfined compressive strength tests were run on soil samples after bringing the moisture content of soil to its optimum, first for ordinary distilled water then using different percentages of dispersion agents. The dispersion agents were mixed with water on a percent by weight basis. First, the soil samples were compacted in the Rainhardt compaction machine according to the standard Proctor Method, and then the unconfined compressive strength of these soil cylinders was found by testing them under an ordinary direct load pressure machine by applying the load vertically. For unconfined compressive strength tests, only 0.5 percent by weight of dispersion agents were used.

Dispersion agents and their percentages, as used in the permeability determinations, and also the American Association of State Highway Officials designations used for the laboratory tests are listed below:

1.0	percent	Tetrasodium	Pyrophosphate	Granular
0.5	"	"	"	"
1.0	"	Sodium	Tripolyphosphate	Granular I
0.5	"	"	"	"
1.0	"	Sodium	Hexametaphosphate	buffered with Sodium carbonate
0.5	"	Sodium	Hexametaphosphate	buffered with Sodium carbonate

The AASHTO Designations referred to for the laboratory tests are,

Specific Gravity Test	AASHTO DES.	T-100-54
Field Moisture Equivalent	"	" T-93-54
Atterberg Limits:		
Liquid Limit	"	" T-89-54
Plastic Limit	"	" T-90-54
Shrinkage Limit	"	" T-92-54
Hydrometer Analysis	"	" T-88-54 (except stirring time, 2 min.)
Compaction Tests	"	" T-99-49 (except Rainhardt compaction machine was used)

DISCUSSION

The results of the tests, made on the permeability and unconfined compressive strength of the soils used during this research, are shown in the graphs plotted.

Fireman and Magistad (2), in studying the permeability of five western soils as affected by the percentage of sodium of the irrigation water, found out and stated that there was no sharp break in the permeability curves as percentage of sodium in the waters was increased. This can be also noticed in the graphs plotted in this paper. As the percentage of dispersion agent was increased, the permeability decreased, following a smooth curve. It can also be noticed from the graphs that the curves tend to approach a horizontal asymptote. This shows that there is some sort of a functional relationship between the percent dispersion agent and the decrease in permeability.

By studying the results, it can also be seen that the percent reduction in permeability of soil types (A and B) containing greater amounts of colloids is greater than the ones containing less colloids, although there might be exceptions. One dispersion agent doesn't show the same effect on the different types of soils. This is due to the fact that all soils do not act the same, due to their different structure and composition (2).

The addition of dispersion agents to the different soils used during this research decreased the permeability of all the soils to some extent. However, the results obtained do not furnish any basis for prediction of the reduction in permeability that may be obtained by the

use of a specific amount of dispersion agent.

Another phase of this research work was also to study the effects of dispersion agents on the strength characteristics of different types of soils used during this work.

Unconfined compressive strength tests were made and the shear strengths of the soils are given in Table 4, and also by graphs.

It was found that the effect of dispersion agents on the shearing strength of soils was not very great. The soils (A and B) containing a greater amount of colloids were affected more than the soils (C and D) containing less amount of colloids. Especially, it can easily be noticed that the effect of dispersion agents on soil types of C and D is almost none. Lambe (6), by carrying his work to a further point on this type of work and studying the dry-and-wet cycles of dispersant-treated soils, found that the unconfined compressive strength of the dispersed soil was higher than that of the untreated soil. This indicates that the soils treated with dispersion agents may, in time, recover their strength.

This work was carried to determine whether dispersion agents decrease the permeability of soils without decreasing their strength, because if we can reduce the permeability of soil to a very low value by using dispersion agents, then it will be one of the most economical ways to make an impervious core for a dam, to build an impervious blanket, or to reduce seepage by injecting the dispersant into the soil through well points.

The treatment of dispersion agents to soils is very practical because they can either be mixed with water on percent by weight basis

or spread over the soil in powder form as the situation would desire.

CONCLUSIONS

The main factors that affected the permeability of the soils in this work were most probably the ion exchange and the structure of the soil itself. It would be much better to study the above two phenomena in order to explain why dispersion agents decrease the permeability of soils.

When we treat the soil with dispersion agents, which were sodium compounds in this case, then an ion exchange process occurs between the anions of the sodium compound and the positive ions attached to the colloids in the soil (Lee 7). This chemical process helps the soil to disperse itself. Lambe (6) explains this process of reduction of permeability by stating that when dispersion agents are added to soil, the soil particles arrange themselves in a more regular form due to the unlike charges of the molecules in the solutions and thus creating a higher effective surface in the dispersed soil sample. When the soil particles are arranged more regularly, the resistance to seepage is increased so this causes a decrease in permeability.

The reduction in permeability can also be explained in another way. When the sodium ions take the place of the hydrogen ions or the calcium ions around the soil particles, the particles are charged with the same charge, and this causes the soil particles to repel each other and thus deflocculation occurs. This means that the aggregations of particles are broken down to smaller sizes. In this case, though the percent of voids in the soil is not changed, the hydraulic radius is tremendously decreased, and the surface bound to water is greater, and, of course, this causes a

reduction in permeability of the soil.

Lee (7) gave another explanation to the reduction of permeability of soils when treated by sodium compounds. According to him, if the excess sodium ions that stay in soil after the ion exchange phenomena are removed from the soil by leaching with water, the colloidal aggregates disperse, and this changes the physical characteristics of soil and thus the voids of the soil are filled with a sticky gel which decreases the permeability of soil, since this substance is impervious to water.

As a result of these explanations, it can be stated that the dispersion agents decrease the permeability of soils due to their effect on the structure and chemical characteristics of the soils, but the effect of each dispersion agent on different types of soil is different due to the different characteristics of soils.

As a result of the study of the shearing strength versus percent dispersion agent curves, it can be said that the dispersants have almost no effect on sandy soils, though they decrease the shear strength of colloidal soils to some small extent. This might be due to the fact that the colloidal soils have a greater tendency to hold water, and when dispersant is added this tendency increases, and the shearing strength of all soils depend largely on their water content.

It would be wise to run laboratory tests on soil samples before any further work is done in the field, since the shear strength is perhaps the most important characteristic property in engineering practice.

ACKNOWLEDGMENT

The writer wishes to express his gratitude and appreciation to Professor Harold H. Munger for his kind help in carrying on this research work, and the writing of this paper.

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APPENDICES

LOCATION OF SOIL SAMPLES USED
IN THIS RESEARCH PROJECT

- Sample A: Sec. 1, T 10S, R 7E
South backslope of township road,
1/8 mile NW of Radio Tower of Station KSAC
- Sample B: SW 1/4 of SE 1/4, Sec. 2, T 10S, R 8E,
600 ft. north of Highway US 24.
- Sample C: NW 1/4 of Sec. 28, T 10S, R 8E,
East backslope of Highway K-13, 6 ft. above
the centerline grade, 1/4 mile south of
NW corner of Sec. 28.
- Sample D: NE 1/4 of Sec. 28, T 10S, R 7E,
South backslope of old Golden Belt Road,
1/4 Mile east of entrance to I.O.O.F. Home.

Table 2. Summary of the classification tests.

	Sample			
	A	B	C	D
<u>Simple tests:</u>				
Specific Gravity	2.54	2.75	2.73	2.87
Field Moisture	39.80	36.84	53.10	33.30
<u>Classification tests:</u>				
Liquid Limit	38.20	40.10	33.70	30.50
Plastic Limit	21.80	20.70	42.30	45.40
Shrinkage Limit	21.20	24.30	23.70	25.00
<u>Hydrometer analysis:</u>				
Sand, percent	2.0	3.5	21.0	48.0
Silt, "	50.5	49.0	33.0	26.0
Clay, "	47.5	47.5	46.0	26.0

Classification of the Soil Samples

Sample	U. S. Bu. of Public Roads	Description of Soil
A	Silty Loam	Reclaimed by tile drainage 45 years previous to sampling.
B	Silty Loam	Swamp, subjected to intermittent flooding.
C	Clay Loam	Formed by disintegration of marine shale of Permian age.
D	Sandy Loam	Alluvium flood plain deposit of Kansas River.

Table 3. Summary of the permeability values obtained from the tests.

	Samples			
	A	B	C	D
Ordinary distilled water: Permeability, (cm/min.)	1.11×10^{-5}	1.19×10^{-5}	1.31×10^{-4}	3.75×10^{-5}
Tetrasodium Pyrophosphate Granular: 0.5% by weight, Permeability, (cm/min.)	1.40×10^{-6}	1.21×10^{-6}	7.02×10^{-6}	1.46×10^{-6}
Tetrasodium Pyrophosphate Granular: 1% by weight, Permeability, (cm/min.)	7.98×10^{-7}	9.43×10^{-7}	9.25×10^{-7}	8.31×10^{-7}
Sodium Tripolyphosphate, Granular I: 0.5% by weight, Permeability, (cm/min.)	1.31×10^{-6}	2.46×10^{-7}	5.80×10^{-6}	3.12×10^{-6}
Sodium Tripolyphosphate, Granular I: 1% by weight, Permeability, (cm/min.)	6.66×10^{-7}	2.07×10^{-6}	1.27×10^{-6}	1.12×10^{-6}
Sodium Hexametaphosphate buffered with Sodium Carbonate: 0.5% by weight, Permeability, (cm/min.)	1.45×10^{-6}	2.90×10^{-6}	3.92×10^{-6}	3.97×10^{-6}
Sodium Hexametaphosphate buffered with Sodium Carbonate: 1% by weight, Permeability, (cm/min.)	8.00×10^{-7}	2.20×10^{-6}	9.00×10^{-7}	8.60×10^{-7}

Table 4. A summary of the shear strength values obtained from the tests.

	Sample			
	A	B	C	D
Ordinary distilled water: Shear strength, psi.	14.3	15.1	11.9	11.9
Tetrasodium Pyrophosphate Granular: 0.5% by weight, Shear strength, psi.	13.5	14.3	11.5	11.9
Sodium Tripolyphosphate Granular I: 0.5% by weight, Shear strength, psi.	12.8	13.9	11.1	11.5
Sodium Hexametaphosphate buffered with Sodium Car- bonate: 0.5% by weight, Shear strength, psi.	12.8	13.5	11.2	11.7

Table 5. The relation of dispersion agent to percent reduction in shear strength.

	Sample			
	A	B	C	D
Tetrasodium Pyrophosphate Granular: 0.5% by weight, Reduction in shear strength, %	5.60	5.30	3.36	0.0
Sodium Tripolyphosphate Granular I: 0.5% by weight, Reduction in shear strength, %	10.50	7.95	7.20	3.36
Sodium Hexametaphosphate buf- fered with Sodium Carbonate: Reduction in shear strength, %	10.50	10.60	5.25	1.05

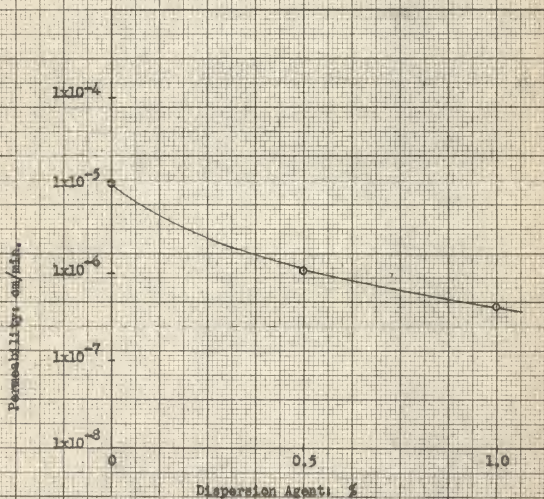


Fig. 2. Sample A: Sodium tripolyphosphate granular I added to distilled water (by wt.).

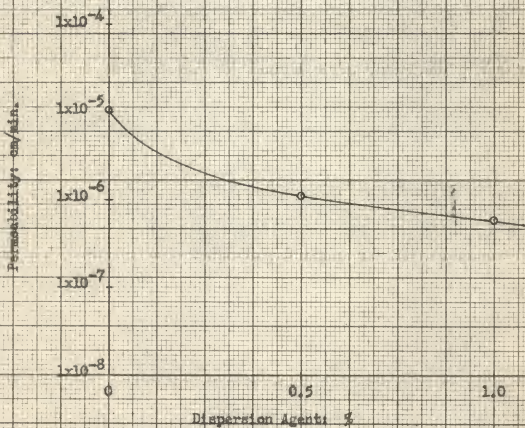


Fig. 3. Sample A: Tetrasodium pyrophosphate granular added to distilled water (by wt.).

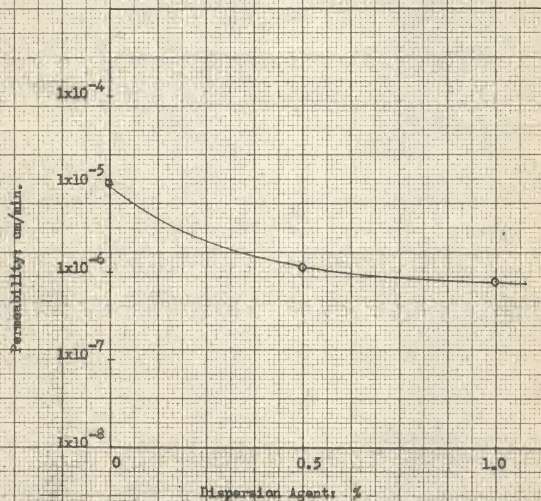


Fig. 4. Sample A: Sodium hexametaphosphate buffered with sodium carbonate added to distilled water (by wt.).

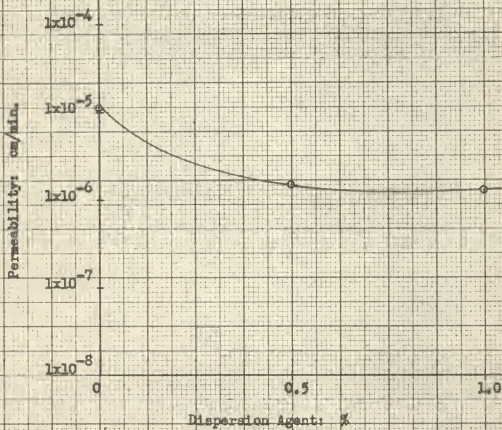


Fig. 5. Sample B: Sodium tripolyphosphate granular 1.

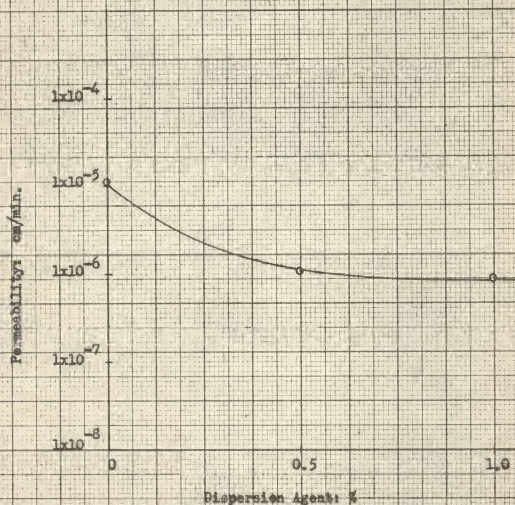


Fig. 6. Sample B: Tetrasodium pyrophosphate granular.

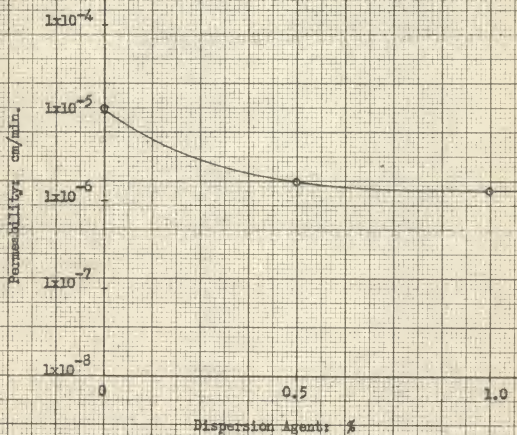


Fig. 7. Sample B: Sodium hexametaphosphate buffered with sodium carbonate.

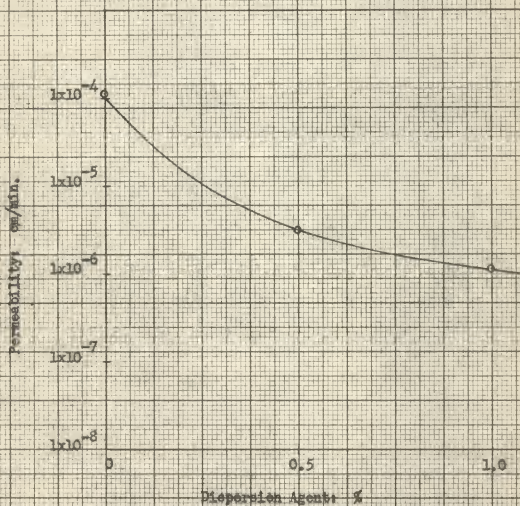


Fig. 3. Sample C: Sodium tripolyphosphate granular 1.

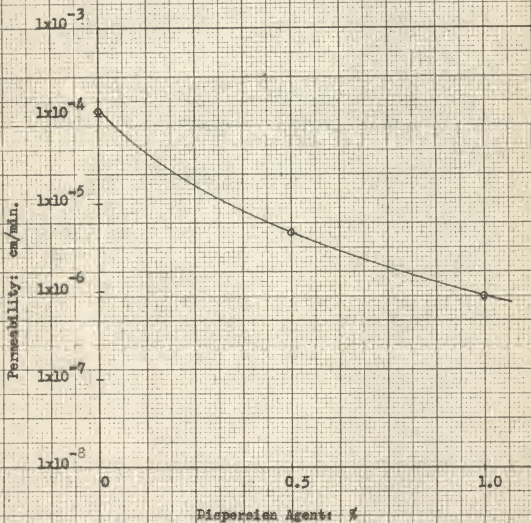


Fig. 9. Sample G: Tetrasodium pyrophosphate granular.

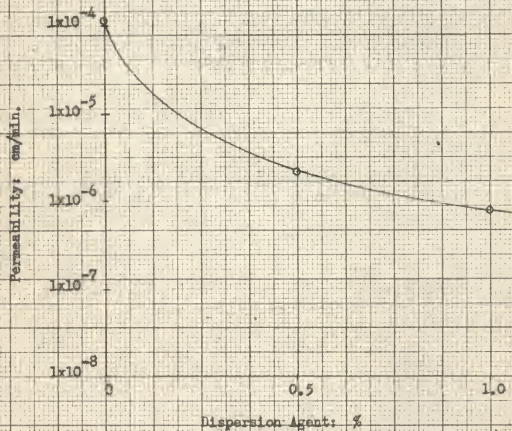


Fig. 10. Sample C: Sodium hexametaphosphate buffered with sodium carbonate.

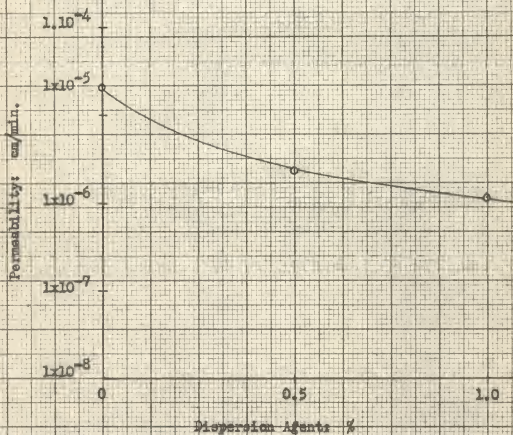


Fig. 11. Sample 2: Sodium tripolyphosphate granular 1.

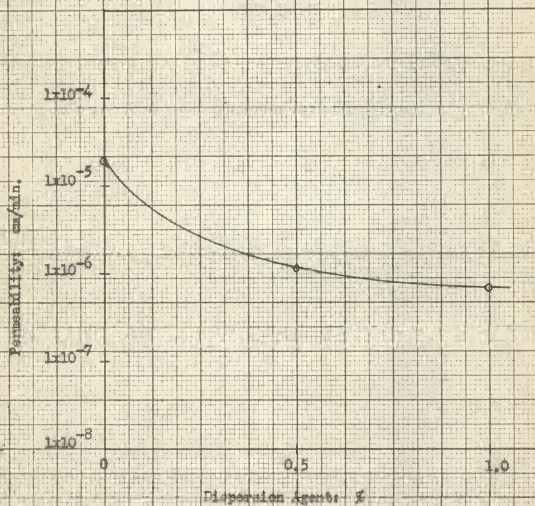


Fig. 12. Sample D: Tetrasodium pyrophosphate granular.

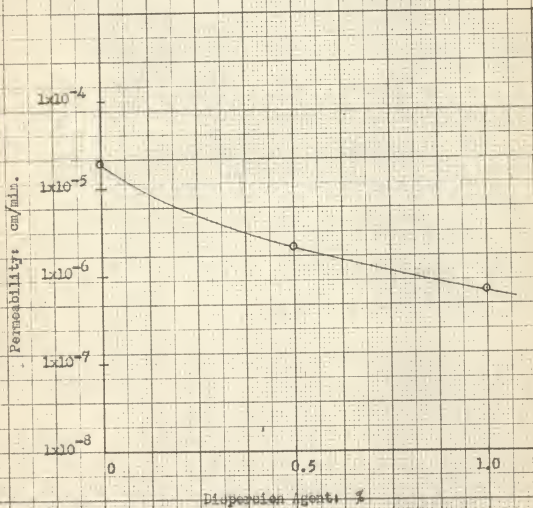


Fig. 13. Sample D: Sodium hexametaphosphate buffered with sodium carbonate.

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As the percentage of dispersion agent was increased, the permeability decreased, following a smooth curve tending to approach a horizontal asymptote. This shows that there is some sort of a functional relationship between the percent of dispersion agent and the decrease in permeability. One dispersion agent doesn't show the same effect on the permeability of different types of soils. This is due to the fact that all soils do not act the same, due to their different structure and composition.

It was also found that the effect of dispersion agents on the shearing strength of soils was not very great. The soils (A and B) containing a greater amount of colloids were affected more than the soils (C and D) containing less amount of colloids.

When the soil is treated with dispersion agents, which were sodium compounds in this case, then an ion exchange process occurs between the anions of the sodium compound and the positive ions attached to the colloids in the soil. Due to this ion exchange the soil particles arrange themselves in a more regular form thus creating a higher effective surface in the dispersed soil sample. When the soil particles are arranged more regularly, the resistance to seepage is increased so this causes a decrease in permeability. Permeability could also have been reduced due to the deflocculation of soil particles caused by excess sodium ions surrounding those particles.

As a result of the shearing strength tests, it can be said that the dispersants have almost no affect on sandy soil, though they decrease the shear strength of colloidal soils to some extent. This might be due to the fact that the colloidal soils have a greater tendency to hold water, and when a dispersion agent is added this tendency increases, and the shearing strength of soils depends largely upon its water content.

It would be wise to run laboratory tests on soil samples before further work is done in the field, since the shear strength is perhaps the most important characteristic property in engineering practice.